RI 306775-53-34
RFP-146

(REVISED) TECHNICAL/MANAGEMENT PROPOSAL
VOLUME I

Cassegrain Feeds for NRAO

For
National Radio Astronomy Observation
Edgemont Road
Charlottesville, Virginia 22901

Attention:
J. Marymor

8 SEPT. 1972

This data furnished in response to RFP-146, shall not be disclosed outside the Government or be duplicated, used or disclosed in whole or in part for any purpose other than to evaluate the proposal, provided that if a contract is awarded to this offeror as a result of or in connection with the submission of such data, the Government shall have the right to duplicate, use, or disclose this data to the extent provided in the contract. This restriction does not limit the right of the Government to use information contained in such data if it is obtained from another source.

RADIATION
A DIVISION OF HARRIS-INTERTYPE CORPORATION

RADIATION
INCORPORATED
SUBSIDIARY OF HARRIS INTERTYPE CORPORATION

SYSTEMS DIVISION
P. O. Box 37 • Melbourne, Florida 32901 • Phone (305) 727-4000

25 July 1972

National Radio Astronomy Observatory
Edgemont Road
Charlottesville, Virginia 22901
Attn: Mr. J. Marymor
Manager of Contracts

Subj: Submission of Proposal RI306755-53-34
"Cassegrain Feeds for NRAO"

Gentlemen:

Radiation, a Division of Harris-Intertype Corporation, is pleased to submit the subject proposal in response to NRAO RFP-146. Six copies of the proposal are enclosed.

The proposed feed designs are based on trade-offs to maximize performance and minimize cost for state-of-the-art components. Minor deviations have been taken from the NRAO specification. These should have virtually no impact on system performance. If, after review of our proposal, there are any questions regarding our technical approach or trade-off analyses, we would be pleased to discuss these matters with you in detail.

Our proposal contains independent prices for a short horn feed (scaled), a long horn feed (scaled), a dual frequency feed (actual size), and a program combining all the preceding. In addition, cost deltas are included in the event that actual size feeds are preferred over the scale models. The savings to be realized as a result of award of all three feeds are shown as a total. A further breakdown of this reduction is not shown; allocation of savings against specific feeds is difficult and arbitrary, since elements of the design, fabrication, test and software associated with each feed have much in common.

Since the terms and conditions of the proposed contract were not a part of the RFP, Radiation reserves the right to review the proposed terms and conditions prior to acceptance of a contract that might result from this proposal. With regard to rights in data, Radiation agrees that all designs, drawings, technical data and feeds furnished to AUI under any resultant contract shall become the property of AUI.

Our proposal is responsive with regard to final inspection and acceptance of deliverable hardware within 60 days after delivery to NRAO. However, we suggest that you consider performance of the foregoing at Radiation on the basis of test equipment and personnel availability.

RADIATION
INCORPORATED

National Radio Astronomy Observatory
Subj: Submission of Proposal RI306755-53-34
"Cassegrain Feeds for NRAO"

This proposal will remain in effect for a period of 90 days.

Should you have any questions or desire any additional information, please contact the undersigned at A/C 305/727-4311.

Sincerely yours,

Jerome P. Stirman, Manager
Surface Operations
Radiation, a Division of Harris-Intertype Corporation

JPS:vb

Enclosures

RADIATION
INCORPORATED
SUBSIDIARY OF HARRIS-INTERTYPE CORPORATION

SYSTEMS DIVISION
P. O. Box 37 • Melbourne, Florida 32901 • Phone (305) 727-4000

27 July 1972

National Radio Astronomy Observatory
Edgemont Road
Charlottesville, Virginia 22901

Attention: Mr. J. Marymor
Manager of Contracts

References:
1) NRAO RFP-146
2) Radiation Proposal, RI 306755-53-34, Cassegrain Feeds for NRAO

Gentlemen:

Per your request today, enclosed are six copies of the technical reference on Page 36 of our proposal for the Cassegrain Feeds for NRAO. Please feel free to contact us directly if there are additional questions or clarifications required.

Very truly yours,

W. G. Premaza

W. G. Premaza
Director, Program Development
Surface Operations

WGP:q

Encs. - 6

ELECTRONIC SYSTEMS, PRODUCTS AND SERVICES FOR GOVERNMENT AND INDUSTRY

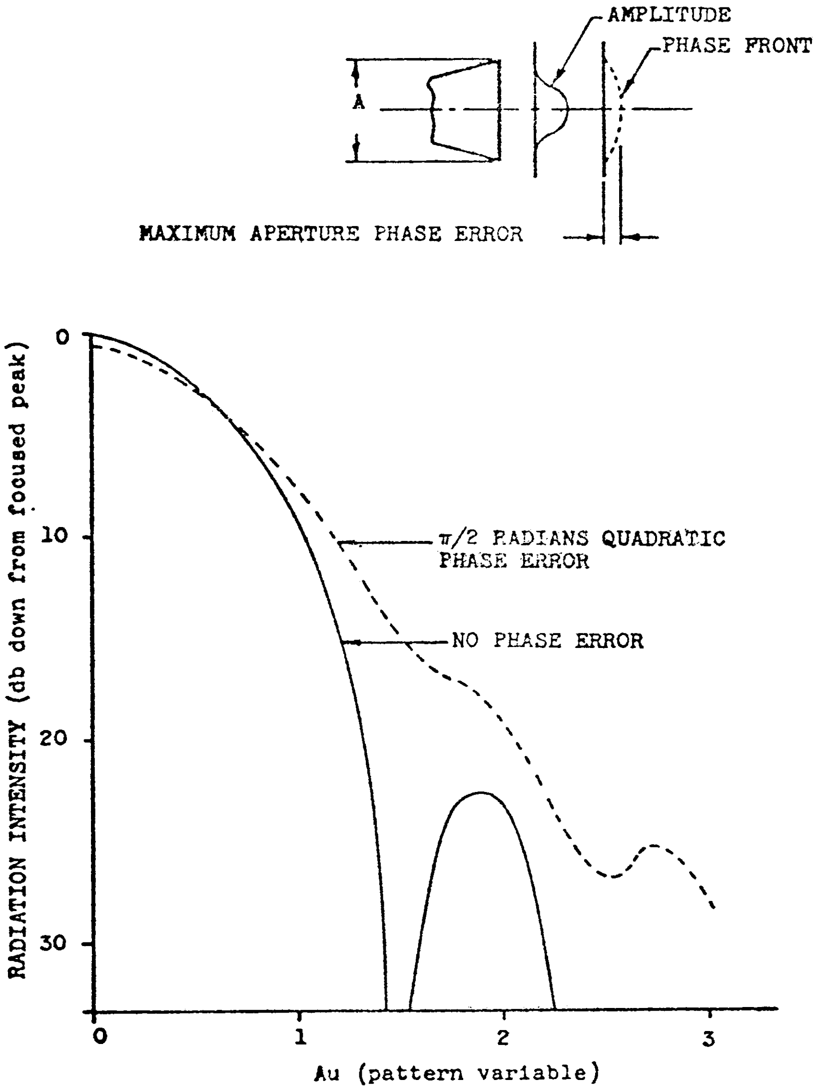
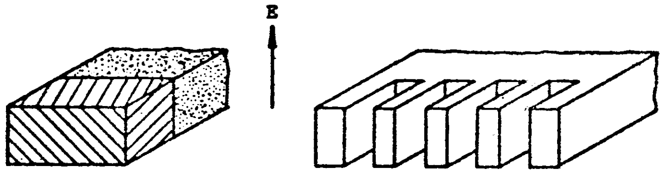


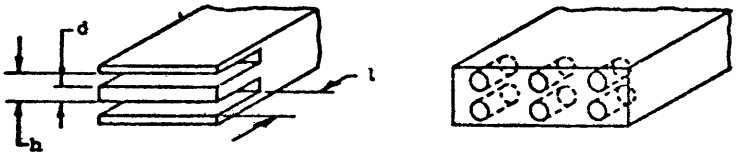
Fig. 1 Focused and defocused radiation patterns.

quick choice of a few standard contours; or, depending on the desired quality of focus, other contours may be determined.

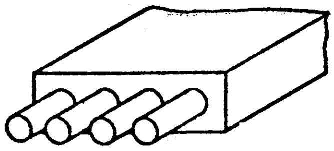
The requirement that the lens surfaces be impedance matched is sometimes neglected in antenna applications. The matching is especially necessary, however, when the lens is used in an H-plane sectoral horn. In this environment, reflections from the lens surfaces, which are generally out of a phase front (defocused), generate higher order waveguide modes which propagate back in the sectoral horn to a point where they are cut off, reflect again, and return to the lens where they again partially reflect, and repeat



(a) Different media. (b) Vertical corrugations.



(c) Horizontal corrugations. (d) Holes.



(e) Posts.

Fig. 2 Simulated transformers for matching dielectric surfaces.

the process. The horn aperture therefore has a composite excitation comprising the desired modes and the undesired modes generated by the multiple reflection. Other detrimental effects of lens reflections are a reduction of radiated power, and a decrease in the power handling capacity of the feed.

The dielectric-air interfaces are most conveniently matched with quarter-wave transformer regions. Fig. 2 shows some of the configurations possible. The regions must be a quarter wave long in the direction of the horn axis, and their impedances must be the geometric mean of the impedances of the bounding regions. Both of these conditions vary along the lens surface as a function of the angle of the incident ray. The H-plane corrugations of Fig. 2c were chosen for the H-plane lens. The relations

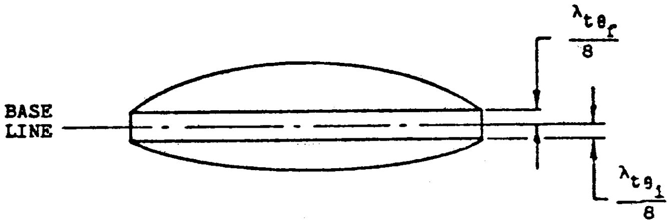
$$\frac{d}{h}=\frac{k_o(k_t-k_o)}{k_t(k_d-k_o)},\ \text{for } h \ll \lambda_o,$$

where k is the relative dielectric constant of the region denoted by the subscript o for air, t for transformer, and d for dielectric, provides the correct transformer impedance and

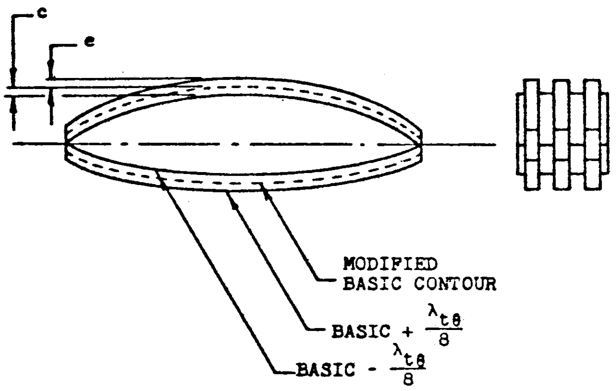
$$l = \frac{\lambda_t}{4}$$

provides the correct transformer length for each ray. Ref. 3 provides relationships for obtaining the proper transformer impedance for h larger than $0.1\ \lambda_o$, as well as for some of the other transformer configurations in Fig. 2.

The application of the transformer region to the lens is accomplished as shown in Fig. 3. To the basic lens contours a theoretical slab whose thickness is the sum of half the maximum transformer lengths of both sides is added. This slab does not change the refractive power of the lens, to a first approximation. The transformer length for each ray is then centered on the modified basic contours. To the extent that the transformer electrical length is a small percentage of the electrical length through most of the lens, and does not change much, the refractive power of the lens is still not altered.



(a) Initial modification of basic contours.



(b) Addition of matching regions to modified contours.

Fig. 3 Application of matching regions to basic lens.

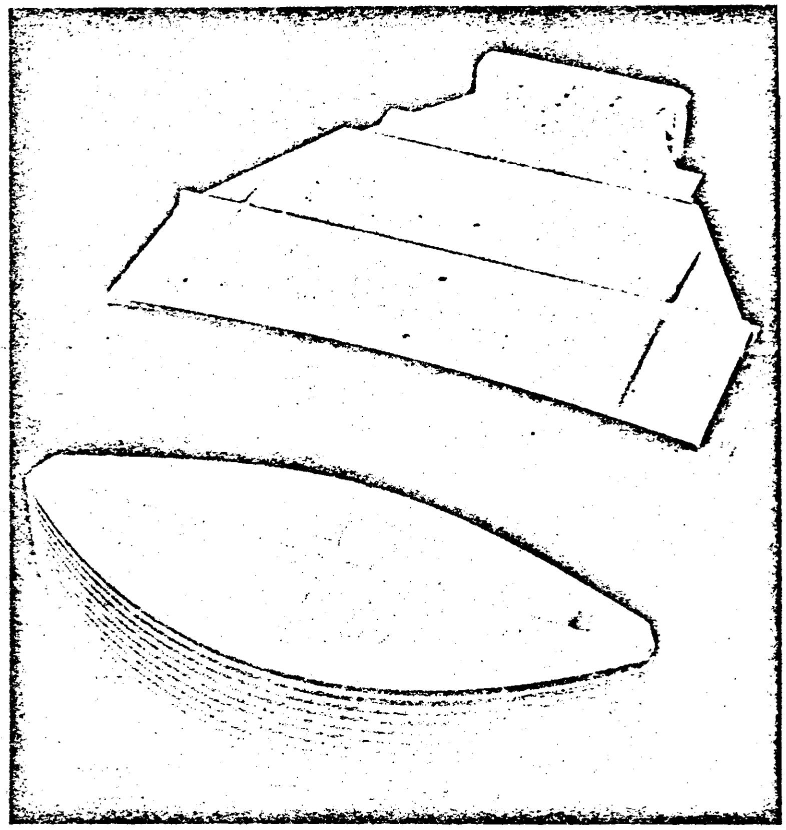


Fig. 4 Lens with sectoral horn.

PERFORMANCE OF THE PHASE CORRECTED HORN

The lens, shown in Fig. 4 with its associated sectoral horn, was made of Teflon. The horn aperture was approximately ten wavelengths wide in the H-plane, and had a total phase error of approximately 500 degrees, resulting from a flare angle of 56° and a distance from the subreflector of 34 wavelengths. Focus was actually obtained at 40 wavelengths; the discrepancy is attributed to the value of dielectric used for the design being higher than the actual dielectric constant. The reflection from the lens within the horn was calculated and measured to be less than 0.4 db SWR over a 9% frequency band.

Fig. 5 shows the radiation patterns obtained from the sectoral horn with lens, compared to the computed focused pattern. The measured patterns approach the computed patterns very closely. The remaining discrepancies are attributed to the distortion of horn excitation caused by a lens which has curvature within the horn (Ref. 2, p. 386). The pattern of the uncorrected horn is also shown for comparison, illustrating the need for the corrective lens.

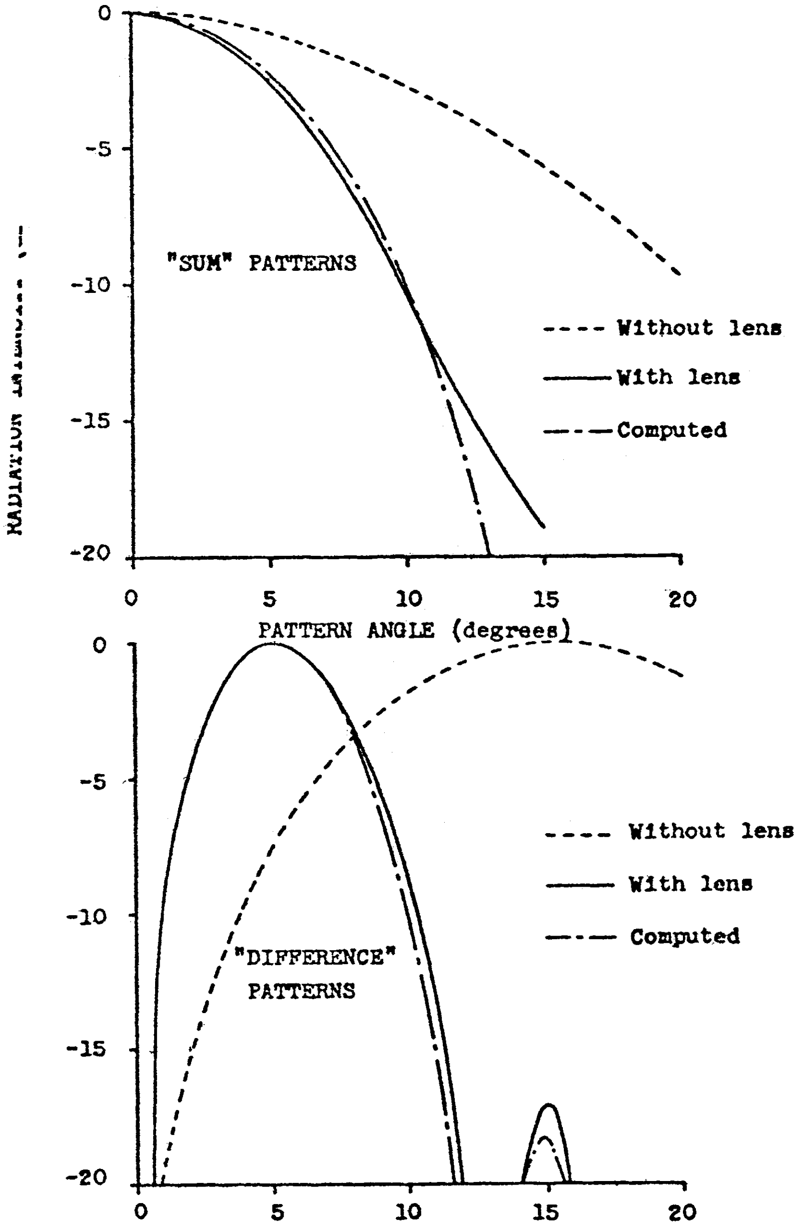


Fig. 5 Radiation patterns of sectoral horn.

ACKNOWLEDGEMENTS

The Wheeler Laboratories design of the aperture lens for an H-plane sectoral horn was performed under subcontract to the Bell Telephone Laboratories, on a prime contract between the Western Electric Company and the U. S. Army.

REFERENCES

1. S. Silver, "Microwave Antenna Theory and Design," 1 ed., *Rad. Lab. Series*, Vol. 12, McGraw-Hill; 1949. (Phase error effects, p. 186–191.)
2. J. D. Kraus, "Antennas," McGraw-Hill; 1950. (Lens Antennas, ch. 14.)
3. T. Morita, S. B. Cohn, "Microwave Lens Matching by Simulated Quarter-Wave Transformers," *IRE Transactions on Antennas & Propagation*, vol. AP-4, No. 1, p. 33–37; Jan. 1956.
4. T. Morita, S. B. Cohn, E. M. T. Jones, "Measured Performance of Matched Dielectric Lenses," *IRE Transactions on Antennas & Propagation*, vol. AP-4, No. 1, p. 31–32; Jan. 1956.

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1.0 SUMMARY OF EXCEPTIONS

As a result of technical discussions with NRAO personnel and a subsequent review, we recognize the NRAO requirements that led to the severity of specifications; therefore, the original specifications which we consider to exceed the present state-of-the-art will be retained as design goals. Our assessment of what we can guarantee under this effort, however, is summarized as follows:

1.1 Short Horn Feed

Frequency: 1.35 to 1.72 GHz (24%)

Feed Efficiency: 70% excluding mismatch and loss of lens.

Phase Center Deviation from Spherical Wavefront: 15°

Isolation: Without Reflector: 30 dB

With Reflector: Because of the higher order modes generated by the presence of a reflector due to the adverse effect of minor deviations from flatness, we must take exception to the requirement of meeting the isolation with a reflector over the horn. We will make the measurement and report the result, however.

Attenuation (dissipative): Less than .03 dB excluding loss of lens.

Pressurization (psig): <1.0

Mismatch (vswr): <1.5 (including lens)

Physical Size: Less than 2 meters diameter but greater than 2 meters in length.[1]

Lens Loss (dissipative): <0.05 dB over the operating band.

Phase Center Location: We take exception to the phase center location requirement of ±10 cm. However, the phase center location shall be measured and marked for optimum positioning of feed.

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[1] All horns will be designed so that paramps can be located in the same physical location to optimize trade-off in gain-noise temperature performance.

Impact on Noise Temperature: The total resistive loss of horn and lens should not exceed .08 dB which will add less than 5 degrees to the total noise temperature of the system (approximately 55 degrees).

1.2 Long Horn - (K-Band)

Frequency: 20 - 25 GHz

Feed Efficiency: 72%

Phase Center Deviation from Spherical Phase Front: 15°

Isolation: Without Reflector: 30 dB

With Reflector: Exception per short horn

Match (vswr): <1.3 (however over most of the operating band vswr will be less than 1.12).

Attenuation (dissipative loss): <0.15 dB

Pressurization (psig): <1.0

Physical Size: <15 cm diameter length compatible with short horn.

Phase Center Location: We take exception to the phase center location requirement of ±2 cm. However, the phase center shall be measured and marked for optimum positioning of feed.

Impact on Noise Temperature: $<9^\circ$ in a total of 150°

1.3 Dual Frequency Feed

Frequency: C-Band: 4.5 - 5.0 GHz

Ku-Band: 14.4 - 15.4 GHz

	C-Band	Ku-Band
Feed Efficiency (calculated):	71.%	70.0%

(Excluding loss of FSP)

Phase Center Deviation:	15°	15°
Axial Ratio:	0.8 dB	0.8 dB
Isolation: Without Reflector:	19 dB	19 dB
With Reflector:	35 dB	35 dB
Match (vswr):	<1.15	<1.15
Pressurization (psig):	<1.0	<1.0
Physical Size:	0.8 m diameter, compatible with other length horns.	
Attenuation (dissipative):	0.04 dB	.09 dB
Frequency Selective Plate: (Estimate of Resistive Loss:)	0.05 dB	0.1 dB
Impact on Noise Temperature:	<5.4° in 40°	≤11° in 130°
Delivery Schedule for all actual Size Feeds:	9 Months ARO	

2.0 DEFINITION OF DELIVERABLE HARDWARE

The deliverable hardware has been regrouped under four options as follows:

1.0 Item 1: Short Horn L-Band Feed.

The components deliverable are:

- 1.1 Scale Model Horn (Scaled to C-Band)
- 1.2 Scale dielectric lens
- 1.3 Orthomode transducer (scaled)
- 1.4 Full size short horn L-Band horn
- 1.5 Full size lens
- 1.6 Full size orthomode transducer

2.0 Item 2: Long Horn K-Band Feed.

The components deliverable are:

- 2.1 Scale model horn (Scaled to C-Band)
- 2.2 Scaled orthomode transducer
- 2.3 Actual size K-Band horn
- 2.4 Actual size K-Band orthomode transducer

3.0 Item 3: Dual Frequency Antenna Feed.

Components deliverable are:

- 3.1 C-Band Horn
- 3.2 C-Band Polarizer
- 3.3 C-Band Orthomode Transducer
- 3.4 Ku-Band Horn

3.5 Ku-Band Polarizer

3.6 Ku-Band Orthomode Transducer

3.7 Frequency Selective Plate

4.0 Combination (Items 1, 2, and 3)

Components deliverable are:

4.1	C-Band Horn	(3.1)	(Also serves as model of K-Band Horn)
4.2	C-Band Polarizer	(3.2)	
4.3	C-Band Orthomode Transducer	(3.3)	(Also serves as model of L-Band orthomode transducer and K-Band O.M.T.)
4.4	Ku-Band Horn	(3.4)	
4.5	Ku-Band Polarizer	(3.5)	
4.6	Ku-Band Orthomode Transducer	(3.6)	
4.7	Frequency Selective Plate	(3.7)	
4.8	Scale Model L-Band Horn	(1.1)	
4.9	Scale Dielectric Lens	(1.2)	
4.10	Full Size Short Horn	(1.4)	
4.11	Full Size Dielectric Lens	(1.5)	
4.12	Full Size L-Band Orthomode Transducer	(1.6)	
4.13	Actual Size K-Band Horn (Long Horn)	(2.3)	
4.14	Actual Size K-Band Orthomode Transducer	(2.4)	

3.0 ANSWERS TO TECHNICAL QUESTIONS

A number of technical questions were discussed in detail during the August 9 meeting. They are repeated below along with our response.

3.1 What is the resistive loss in the frequency selective reflector and how will it affect the noise in the system?

This problem was discussed with Dr. Ben Munk of the Electro Science Laboratory of the Ohio State University who wrote his dissertation on the effect of multilayered cross dipoles and their complements. It was his opinion (with which Radiation engineers concur) that the resistive loss is going to be < 0.1 dB; a precise number will be generated during the contractual effort.

3.2 How do you plan to measure the reflective losses (in the FSP)?

This can be accomplished by measuring the over-all effect by substitution with a solid copper sheet and computing the efficiency from measured patterns of the primary aperture.

3.3 Comments on the phase error introduced by the short horn feed:

As Dr. Napier has pointed out in a technical note, the phase error due to the subreflector being in the Fresnel region of the aperture and the short horn taper can both be corrected by a single lens and would be equivalent to correcting the phase in a "shorter" horn. This is also equivalent to correcting the phase error in a co-phasor aperture when measured in the Fresnel region at a distance smaller than is actually the case. Part of our increased scope in the short horn lens is due to increasing the magnification of the lens to correct for the near field effect as well as the "short horn" effect.

The lens necessary to make a complete correction is very heavy (550 pounds.) and this is not even matched to free space. With additional quarter wave layers of matching dielectric, it would become even heavier.

There may be other ways to accomplish this, e.g., using an artificial dielectric. Also, it would be wise to determine the deviation from a spherical wave front if the phase were only partially corrected. Assuming an aperture distribution that can be integrated when put in Equation (5).

(Dr. Napier's note) one could find the phase of E (θ) at any angle θ at a constant distance R from the focal point of the feed for various degrees of correction to determine how small a correction would still be within the 15 degrees deviation allowed.

When using the choked horn, moreover, the phase error, (because of the other modes present) may be different than is predicted by the simple mechanism for a smooth wall lens. (More detail regarding the short horn lens is contained in the next section).

3.4 Operating the Feed Off-Axis

Preliminary computations indicate that the three feeds mounted side-by-side could be operated simultaneously with multiple beams and with losses of less than 0.15 dB for either the short horn or the long horn due to operating these feeds off-axis. This loss can be reduced somewhat by tilting the subreflector as mentioned in the proposal.

The coma loss may be estimated as follows:

The worst-case coma will result from the highest-frequency offset feed, which is the long horn feed operating at 25 GHz. The long-horn feed is offset approximately 20 inches from the reflector axis. The equivalent focal length Fe is MF_m (M is magnification, F_m is reflector focal length), so that the angular offset in radians is approximately $\frac{20''}{Mfm}$. The beam width is approximately $1.2\lambda/D$ radians, so that the angular offset in beam widths is $\frac{20}{1.2M\lambda(fm/D)}$. For f/D = 0.4, a magnification of 7, and λ = .47" (25 GHz), the offset becomes 12.7 beam widths.

According to Hansen[1], the actual path error produced by coma is $\beta_3 h^{3}/3$, where h is the normalized (to reflector diameter) distance of a point on the reflector surface from the axis, and β_3 is the coma coefficient. The path error is also normalized to reflector diameter. Hansen gives curves, which are reproduced in Figure 13, of β_3 as a function of off-axis angle. Since the coma loss varies inversely with magnification, the coma loss of Hansen's M = 4 case may be taken as a worst-case approximation. It can be seen from the curve that the coma coefficient for the M = 4 Cassegrain antenna at a given angle from boresight is less than that for apex fed parabola, f/D = 0.5, at 1/5 that angle. The coma loss of the M = 4 Cassegrain case 12.7 beam widths from boresight is then less than that for the apex fed f/D = 0.5 case at 12.7/5 = 2.5 beam widths from boresight. Figure 10 shows that this loss is about 1 percent, or 0.05 dB. The actual case will probably be less than 1/2 this amount because of the greater magnification.

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[1] Hansen, R.C., Microwave Scanning Antennas I, Academic Press, N.Y., 1964, Pages 140 - 143.

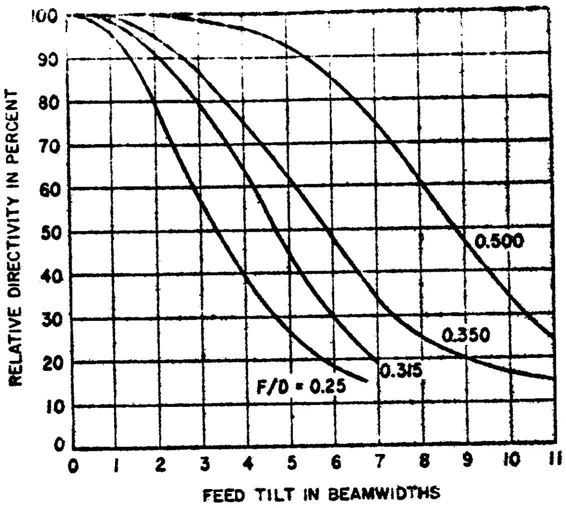

Figure 10. Loss in Directivity of a Paraboloid as of Feed Tilt

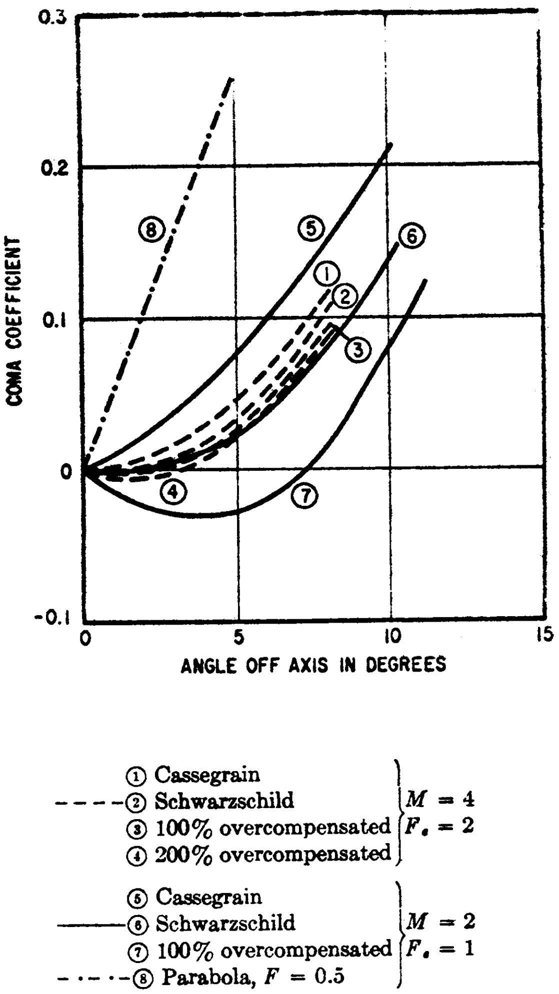

Figure 13. Coma Coefficient Versus Angle off Axis (Normalized for Primary Focal Length of 0.5)

4.0 SHORT HORN DIELECTRIC LENS AND SURFACE MATCHING TECHNIQUE

In order to reduce the horn vswr to acceptable level, both the front and rear surfaces of the lens will be "surface matched". Figure 1 shows the geometry. Since the front surface is planar and rays from the source impinge at normal incidence, the design of the matching layer is simple. Its dielectric constant, ϵ_1, is equal to $\sqrt{\epsilon_2}$ and its thickness is $\lambda/4\sqrt{\epsilon_1}$. For the convex surface of the lens, the geometry is not so simple.

The treatment of the convex surface matching for a plano-convex lens begins in a similar fashion to the problem of obtaining the shape of a "two surface" (convex-convex, convex-concave, etc.) lens. A discussion of this problem is found in Silver[1] on Page 394. If all space on one side of a two-surface lens is filled with a material with higher dielectric constant than that of the lens material, the analysis is directly applicable. Referring to Figure 1 and to Silver (Equation 17, Page 394) the equation of the outer surface is

$$(1) \qquad \frac{1}{r}\,\frac{dr}{d\theta} = \frac{\sqrt{\epsilon_1}\,\sin(\theta - \theta^1)}{\sqrt{\epsilon_1}\,\cos(\theta - \theta^1) - 1}$$

where ϵ_1 is the relative dielectric constant of the matching layer. The derivation of this equation is given by Brown[2]. The equation for the coordinates X and Y is

$$(2) \qquad \frac{y - r\sin\theta}{x - r\cos\theta} = \tan\theta^1$$

which is the same as Silver's Equation 18. The condition on the optical paths is only slightly different from Silver's Equation 19, and is

$$(3) \qquad r + \sqrt{\epsilon_1}\,\sqrt{(y - r\sin\theta)^2 + (X - r\cos\theta)^2} - \sqrt{\epsilon_2}\,X = \text{constant}$$

The reason for change of the X term to $\sqrt{\epsilon_2}\,X$ can be easily seen by choosing a maximum lens thickness and writing the equation for the optical path length.

The above equations are not sufficient to describe the lens, and nothing has been said so far about matching the surface reflections. The important criterion for a lens in a horn would seem to be that the total reflected power in any direction is minimized. If the reflected

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[1] Silver, Samuel, Microwave Antenna Theory and Design, M.I.T. Radiation Laboratory Series #12, McGraw-Hill Book Company.

[2] Brown, J., Microwave Lenses, John Wiley & Sons Inc., New York, 1953.

energy goes back toward the origin it will increase the vswr. If it goes off at some other angle, however, it may also end up in the input circuitry as vswr through reflections off the horn walls and the setting up of higher order modes in the horn. At any rate, reflected energy detracts from the overall antenna gain. Two possibilities come to mind; 1) to let the reflection off the inner surface (dashed line Figure 1) be 180 degrees out of phase with the reflection from the outer surface of some other ray (in the r^1 direction) which intersects the outer surface at the same point, and 2) to let the reflection off the inner surface be 180 degrees out of phase with the reflection off the outer surface of some other ray, the outer surface reflection of which is parallel to the inner surface reflection of the original ray after it is diffracted at the outer surface. The second approach would be preferred in a conventional lens antenna arrangement, but the presence of the horn probably makes the first more desirable for the present case. Neither approach completely eliminates all reflections even at the design frequency, with or without a horn. Both approaches afford reductions in reflected energy. The surfaces generated by the two approaches are very similar, because the two reflected rays which are out of phase are very nearly parallel.

Approach #1 is shown in Figure 1. As shown, the two reflected rays we would like to cancel have slightly different directions. This will present no difficulty if we remember that the "ray" corresponding to a finite surface area is really a beam of nonzero beam width. Indeed, the beam width resulting from the infinitesimal incremental areas considered here has fairly large width. The difference in direction is exaggerated in Figure 1. The angular difference is really quite small. For instance, if the lens were approximated with conical surfaces in the region considered, there would be no angular difference.

If the approximation indicated in Figure 2 on the path of the ray reflected from the inner surface ($a = b$) is taken, then the path length condition is

$$2\sqrt{\epsilon_1}\ \sqrt{(y-r\sin\theta)^2 + (x-r\cos\theta)^2} = \Delta r + \lambda/2 \tag{4}$$

If the additional approximation indicated in Figure 2 is made, that is

$$\Delta r = \left(2\sqrt{(y-r\sin\theta)^2 + (x-r\cos\theta)^2}\right)\left(\frac{dr}{\sqrt{dr^2 + (rd\theta)^2}}\right) \sin i \tag{5}$$

then it remains only to find i.

It can be seen from Figure 1 that the angle at which the direct ray emerges into the dielectric of ϵ_2 is simply the angle of the normal to the inner surface. Then, by Snell's law

$$\sin i = \frac{\sqrt{\epsilon_2}}{\sqrt{\epsilon_1}}\ \frac{{}^{y}dy}{\sqrt{dx^2 + dy^2}} \tag{6}$$

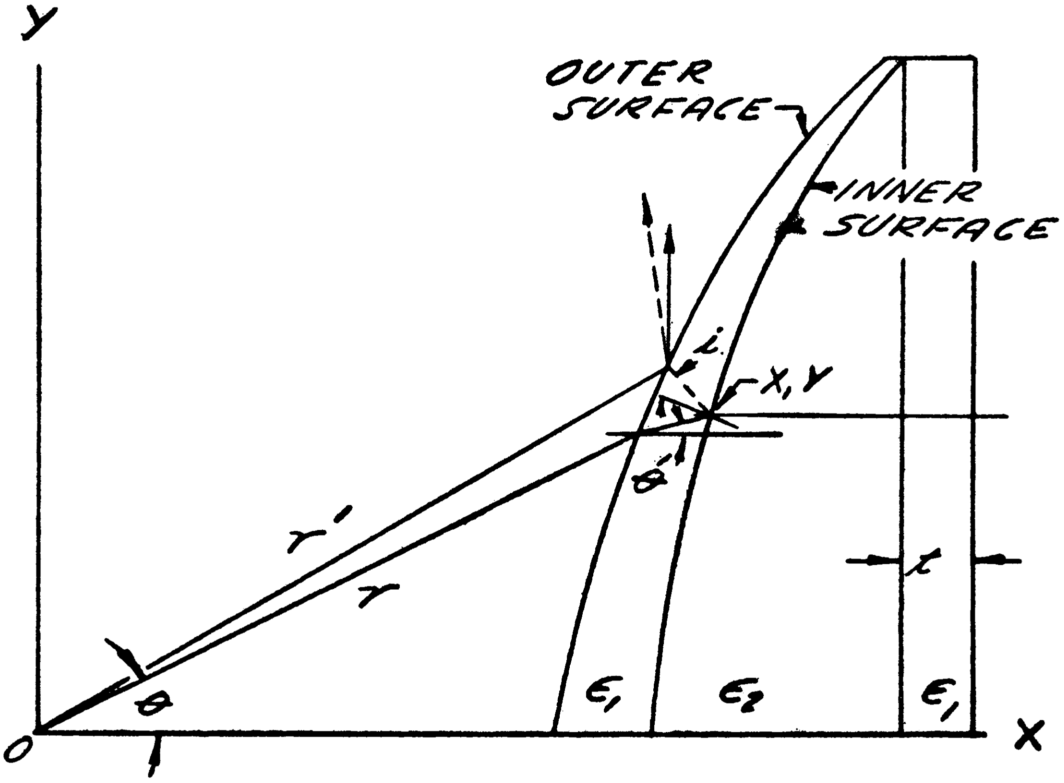

Figure 1

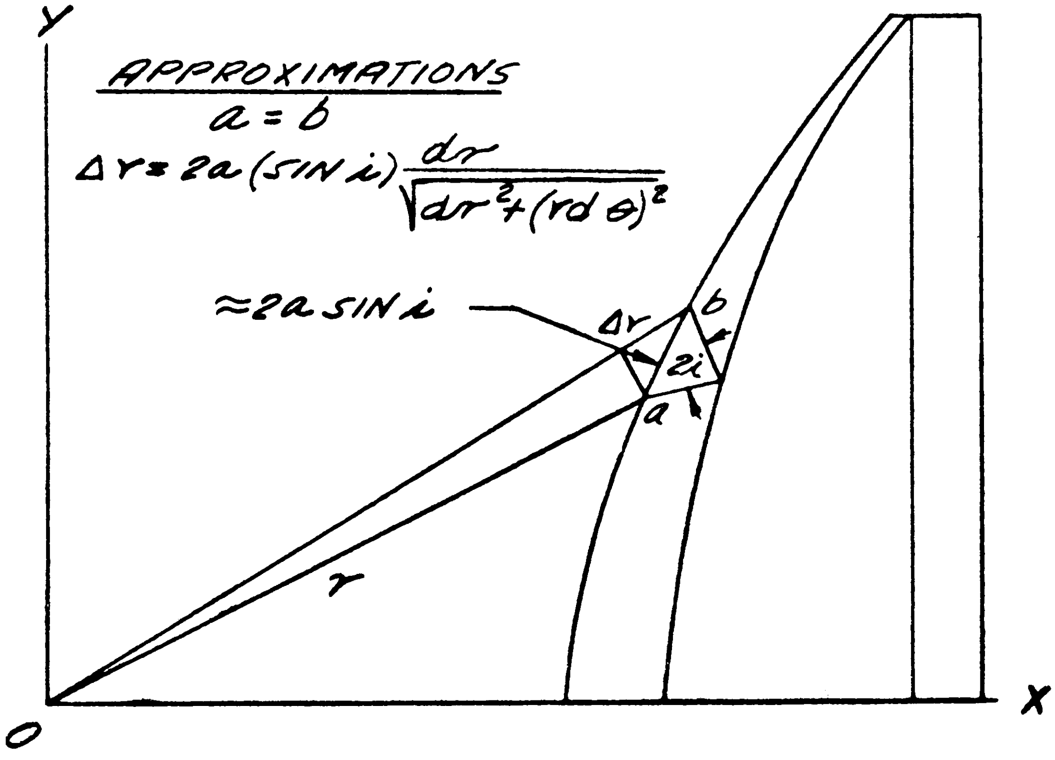
Y
APPROXIMATIONS
$a = b$
$\Delta r = 2a(\sin i)\frac{dr}{\sqrt{dr^2+(rd\theta)^2}}$
$\approx 2a \sin i$
Δr
b
$2i$
a
r
O
X

Figure 2

substituting (6) in (5), and then (5) in (4) results in the condition

$$(7)\qquad 2\sqrt{\epsilon_1}\sqrt{(y-r\sin\theta)^2+(x-r\cos\theta)^2} = \left(2\sqrt{(y-r\sin\theta)^2+(x-r\cos\theta)^2}\right)$$

$$\left(\frac{dr}{\sqrt{dr^2+(rdx)^2}}\right)\left(\frac{\sqrt{\epsilon_2}}{\sqrt{\epsilon_1}}\qquad \frac{{}^{y}dy}{\sqrt{dx^2+dy}}\right)+\lambda/2$$

This equation represents the final condition which, with Equations 1, 2 and 3, define the lens surfaces. The approximations taken in the derivation of the above Equation (7) will result only in incomplete cancellation of reflected rays, and will not affect the focusing properties of the lens, which are guaranteed by Equation (3). The set of Equations (1), (2), (3), and (7) are complicated, and must be solved by computer using iterative techniques.

Materials

The dielectric constant of the matching surface layer should be the square root of the dielectric constant of the lens material. If the lens material has a dielectric constant of 2.5, the surface layer should have a dielectric constant of 1.6. Emerson and Cuming has a material called Ecofoam P.S., which is available with a dielectric constant of 1.6, or any other dielectric constant less than 2.5. Another technique called simulated quarter-wave transformers described by Jones, Morita, and Cohn[3,4] is applicable. It consists of grooves or holes approximately $\lambda/4$ deep in the lens surface, or ports over the lens surface, the distribution of the grooves, holes, or posts being selected to produce the required effective dielectric constant.

Because of the lens weight, it may be desirable to use artificial dielectric for both the lens and the matching layers, an artificial dielectric lens could probably be made with weight less than 50 pounds. Before a decision is made to use this approach, however, a thorough analysis would be made to ensure that the dissapative loss is, indeed, low[5]. Several configurations of artificial dielectric would be considered.

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[3] Jones, E.M.T., Morita, T., and Cohn, S.B., "Measured Performance of Matched Dielectric Lenses; "I.E.E.E., P.G.A.P. Volume AP4, No. 1, January 1956.

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[4] Morita, T. and Cohn, S. B., "Microwave Lens Matching by Simulated Quarter-Wave Transformers", I.E.E.E. P.G.A.P. Volume AP4, No. 1, January 1956.

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[5] Emerson and Cummings have an artificial dielectric which weighs 3 pounds/cubic feet, and claim a dielectric constant of 1.9 and loss tan δ = .0002, at 1.5 GHz.

5.0 REPRICING AND DELIVERY OF NEW OPTIONS

During the August 9 meeting with NRAO personnel, it was stated by NRAO personnel that even though scaled models were to be used in the development of the L-band Short Horn and the K-band Long Horn, a full size L-band Horn and an actual size K-band Horn would definitely be required.

It was further agreed that the actual size models delivered should be prototypes of high quality with enough durability and reliability for three years of field experiments, and be truly representative of the feeds that could be economically produced in quantities of 30 which were tabulated in Section 2.0.

This limited the number of options to four, they are:

5.1 Short Horn L-band Feed, including development models and full size prototype.

5.2 Long Horn K-band Feed including development models (scaled up versions) and actual size prototype.

5.3 Dual Frequency Feed operating at C-band and Ku-band. The prototype will have been developed in their actual sizes. This option includes the Frequency Selective Plate, and a small passive flat reflector needed to form the dual frequency feed combination.

5.4 Combination of the above, including the scale models used in the development. The combination does not include as many deliverable items as would be obtained when purchasing the above three options one at a time. That is because some of the development models are common to more than one feed.

A breakdown for each of the four options including purchased parts, direct engineering labor, engineering overhead, other costs, general and administrative expenses and profit, is provided in a separate volume. This replaces Exhibit 1, Cost Summary in the Financial Proposal.

6.0 COST ESTIMATE OF 30 SETS OF ACTUAL SIZE PRODUCTION FEEDS FOR DELIVERY IN 1975

This information is provided in the revised Financial Proposal.